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The Arrangement of Instruments, the Distance Between Instruments, and the Position of Instrument Pointers as Determinants of Performance in an Eye-Hand Coordination Task

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THE ARRANGEMENT OF INSTRUMENTS, THE DISTANCE BETWEEN INSTRUMENTS, AND THE POSITION OF INSTRUMENT POINTERS AS DETERMINANTS OF PERFORMANCE IN AN EYE-HAND COORDINATION TASK

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FEBRUARY 1952

WRIGHT AIR DEVELOPMENT CENTER

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FOREWORD

These experiments were conducted at Antioch College as part of the work accomplished under AMC Contract No. W33-038 ac-19816, Expenditure Order No. 694-31, Principles of Instrument Presentation. At the time the experiments were planned and conducted, Dr. Fitts was AMC project engineer. The authors collaborated in planning the studies and in preparing the present report. Mr. Simon, who was project director at Antioch College at the time, supervised the collation and analysis of the data. Dr. Fitts and Mr. Simon are now at the Ohio State University.

ABSTRACT

Three experiments are reported in which the effects of various visual stimulus patterns formed by different arrangements of instruments and pointers were studied. For the task employed, which was a continuous, dual-pursuit problem, the results of all three experiments are in agreement in indicating that subjects give significantly superior performance when

a. instruments are close together,
b. instruments are aligned horizontally, and
c. pointers are aligned at 9 o'clock for horizontally-separated instruments and at 12 o'clock for vertically-separated instruments, or else the pointers are counterpoised.

The results of an extended learning study indicated that differences in the initial performance of individuals when using the different pointer-position patterns actually increased during fifteen daily practice sessions.

PUBLICATION REVIEW

Manuscript copy of this report has been reviewed and found satisfactory for publication.

FOR THE COMMANDING GENERAL:

Robert H Blount

ROBERT H. BLOUNT
Colonel, USAF (MC)
Chief, Aero Medical Laboratory
Research Division

CONTENTS

THE ARRANGEMENT OF INSTRUMENTS, THE DISTANCE BETWEEN INSTRUMENTS, AND THE POSITION OF INSTRUMENT POINTERS AS DETERMINANTS OF PERFORMANCE IN AN EYE-HAND COORDINATION TASK

I. INTRODUCTION

Performance in skilled tasks requiring the adjustment of instruments or other visual displays is considerably influenced by the particular stimulus-pattern provided by the display. Among the various problems in this area, one that has received a good deal of systematic attention is the effect of the direction of movement of, and the spatial relations between, displays and controls. Results from such studies have been the subject of recent reviews by Gardner (7), Mitchell and Vince (11), and Fitts (4, pages 1306 to 1311).

Warrick (13) has determined population stereotypes in moving rotary controls in response to different patterns of light, and Carter and Murray (1), Fitzwater (5), Gardner (7), Grether (8), Loucks (10), Mitchell and Vince (11), Simon (12), and Warrick (14) have studied performance in perceptual-motor tasks in relation to various pattern arrangements of controls and displays.

The evidence from these studies indicates that the following spatial factors are important determinants of performance: (1) whether the display and its control move in the same or move in different planes of space; (2) whether the movements are translatory or rotary; (3) whether the display is above or below, to the right or to the left, in front of or behind its associated control; (4) whether or not, when its related control is moved, the direction of the movement of a display is the 'expected' one, i.e., conforms to a population stereotype. It also appears that performance is more markedly affected by such factors when the task is complex and requires frequent change of set.

Connell and Grether (2), Warrick and Grether (15), and White (16) have reported differences in the ability to check-read and interpret instrument dials quickly, depending on the sector of the dial in which the pointer was located.

The three experiments reported here were undertaken to determine the inter-relation of several of these stimulus-pattern factors in a more complex pursuit task than that employed in any of the previous studies except that of Gardner. The variables studied were (a) the direction of pointer alignment, (b) vertical versus horizontal separation of instruments, and (c) the distance between instruments.

II. APPARATUS AND TASK

The Grether Dual-Pursuit Apparatus (9) was used in these studies. In order to operate this apparatus, subjects must watch the pointers on two different dials and try to keep them centered continuously within designated limits by making appropriate adjustments of two rotary control knobs, one of which is operated by each hand.

A drawing of the apparatus is shown in Figure 1. It operates in the following manner: Disturbances, generated by a motor-driven cam, are transmitted to two differential gears. The movements of each of the control knobs are transmitted to one of these differentials. The output of each differential is proportional to the difference between these two inputs, i.e., to the difference between the movements controlled by the cam and the subject's movements. These outputs are transmitted to two instruments dials by electrical synchro systems, where they appear as pointer deflections; they also are transmitted mechanically to wiper arms that move across metal contacts, and activate scoring clocks. The instrument dials are marked so that subjects can tell when the pointers are 'on target'.

Two scoring clocks, one for each of the two differentials, cumulate time whenever the pointers are within the target limits. These 'on-target' scores indicate the cumulative time that the respective pointers have been maintained within their tolerance limits. A third clock cumulates time whenever both pointers are simultaneously 'on target'. The reading of this third clock was used as the criterion of proficiency throughout the present investigations.

Work and rest periods were governed by a sequence timer, which also triggered a warning sound before the beginning of each trial.

Instrument dials were three inches in diameter, black with white pointers, and mounted on a black instrument panel. Four lights in standard reflectors, one at each corner of the panel, provided an even, non-glare source giving an apparent brightness of 30 foot-lamberts. The subject's eyes were 28 inches away from, and at the same height as, the mid-point between the two instruments.

The panel on which the control knobs were mounted was tilted away from the subject at a 45 degree angle, as seen in Figure 1, in order that the knobs could be grasped in a comfortable manner. Adjustable arm rests were used. One control knob was above and to the right of the other, the line formed by the two knobs making an angle of 45 degrees with the base of the panel. The upper right-hand knob was used to control either the upper or the right-hand instrument (depending on whether the two displays were separated vertically

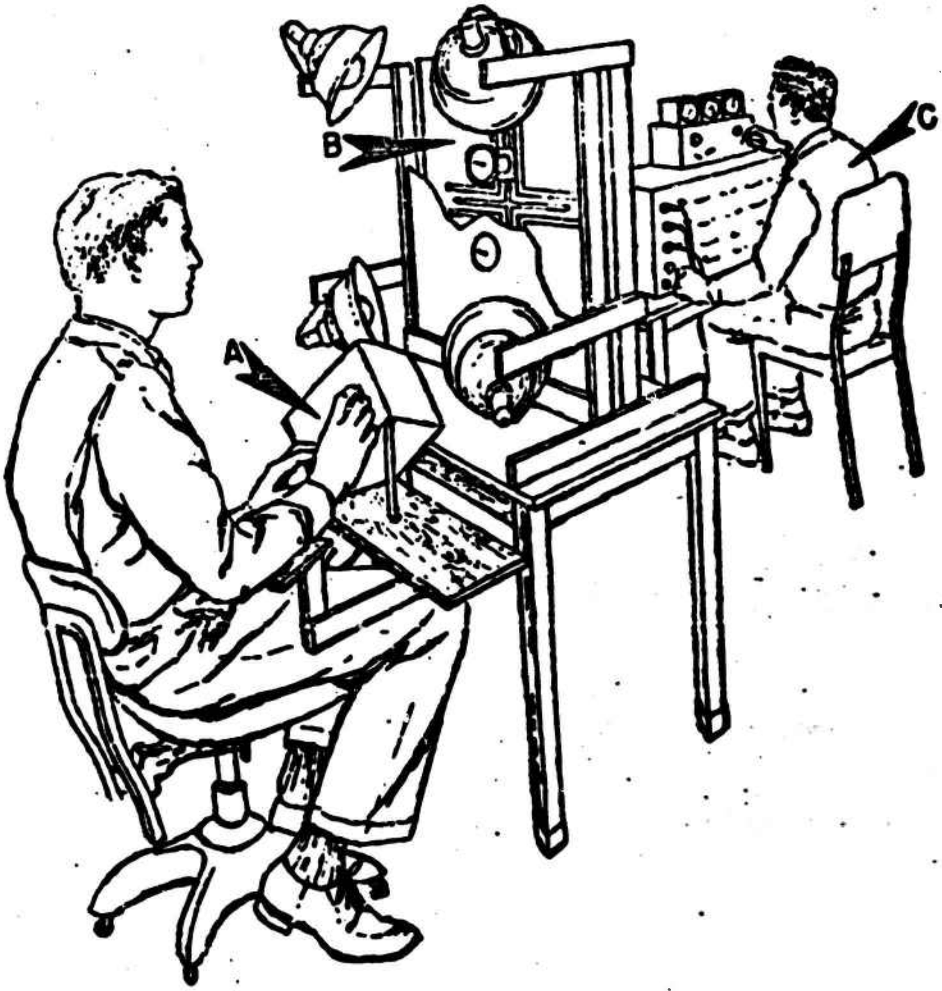

Figure 1. The Grether Dual-Pursuit Apparatus.

The control-box and the two control knobs are shown at "A"; the instrument panel, cut away to reveal the method of mounting the instruments, is shown at "B"; the experimenter, timer, and scoring clocks are shown at "C".

or horizontally), and the lower left-hand knob was used to control either the lower or the left-hand instrument. This arrangement of controls was used throughout the three experiments. Insofar as could be determined, all subjects found this arrangement a natural or expected one, and immediately associated each control with its related instrument.

III. EXPERIMENT 1: A STUDY OF THE RELATIVE EFFICIENCY OF TEN DIFFERENT POINTER-POSITION PATTERNS

Procedure.

Ten stimulus configurations were studied in the first experiment. These patterns are shown schematically in Figure 2. Two directions of dial separation, vertical (V) and horizontal (H), and five different positions[1] of the two pointers, were studied. The pointers were aligned at 3 o'clock, 6 o'clock, 9 o'clock, and 12 o'clock, respectively, and also with their tips counterpoised (directed toward each other). These pointer positions will be referred to hereafter as the 3, 6, 9, 12, and X positions. In the first experiment, the tips of the two pointers were separated by a distance of eight inches.

Twenty male and twenty female college students served as subjects. All had normal visual acuity. None had operated the apparatus before. They were given the following instructions while seated at the apparatus:

> "Your head is now at the correct distance from the instrument panel. Try to keep it at this distance.
>
> "These pointers will move back and forth. Try to keep them within the white reference marks by moving these knobs in the appropriate direction. Try them." (At this point subjects were allowed to turn the knobs and to note the resulting movements of the pointers.)
>
> "Try to keep both pointers on their respective white marks <u>at the same time</u>. The time you

- - - - -

1 Reference throughout the paper to 'pointer position' will be used for convenience to refer to the position of the target or zero point in the quadrant of the dial in which the pointer is functioning. This was always at one of the four cardinal positions. In reality, the position of the pointer was constantly shifting and only rarely, except through the effort of the subject, was it positioned exactly at any cardinal point.

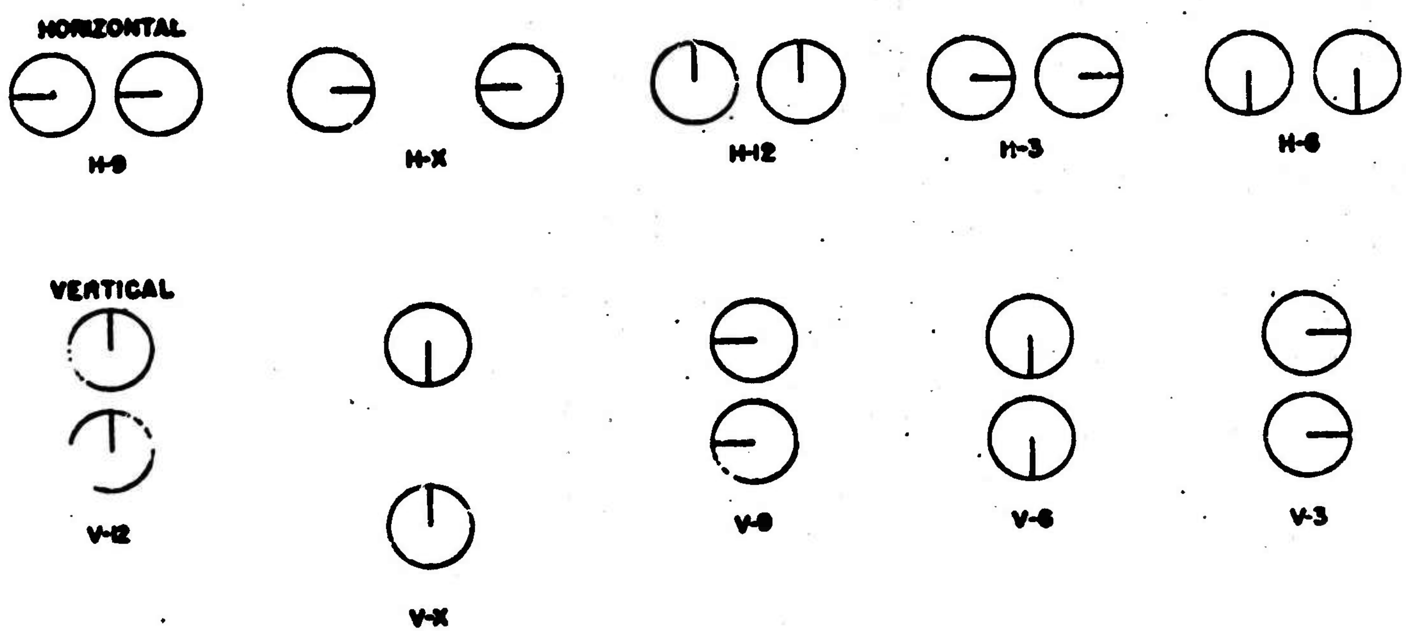

Figure 2. The Ten Different Stimulus Patterns Employed in Experiment 1.

keep them <u>both</u> on will be recorded. You will have ten trials, each followed by a short rest period. After the fifth trial you will be given a longer rest period. Do not turn the knobs during the rest period. A buzzer will warn you a second before the rest period is over. Experience suggests that it is more efficient to move your eyes back and forth between the two dials than to attempt to watch both dials out of the corners of your eyes. So move your eyes as you work.[1]

"The position of the pointers will be changed from trial to trial."

One group always worked with the dials separated horizontally. The other group worked with them separated vertically. Hereafter, these will be called the "H" and the "V" groups. Subjects were assigned to two groups at random, with the restriction that half of each group be men and half be women.

Each subject was given ten 3-minute trials. The first 15 seconds of each trial was treated as a warm-up period, and clock scoring took place only during the last 2 minutes and 45 seconds of each trial. Subjects rested for five minutes between the fifth and sixth trials; after all other trials a 90-second rest period was used.

A different pointer position was presented on each of the first five trials. These five pointer positions were then presented a second time in reverse order. The order of presentation was counterbalanced between the 20 subjects in each group. Completion of the series of ten trials required 50 minutes.

Results.

The experiment was designed to permit combination of the scores made by the same subjects on counterbalanced trials. However, when a performance curve (see Figure 3) was computed by combining mean scores for successive trials without regard to stimulus configurations, it revealed that the combining of the first- and second-trial data would seriously inflate our error term. Learning was quite rapid in the first five trials, and there was still further improvement on the sixth trial which was preceded by the longer rest period. The last five

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1 The instruction to move the eyes was given in order to secure uniformity in the way different subjects worked; actually the experimenters have no data on whether or not subjects do better when they are instructed to move their eyes in this task.

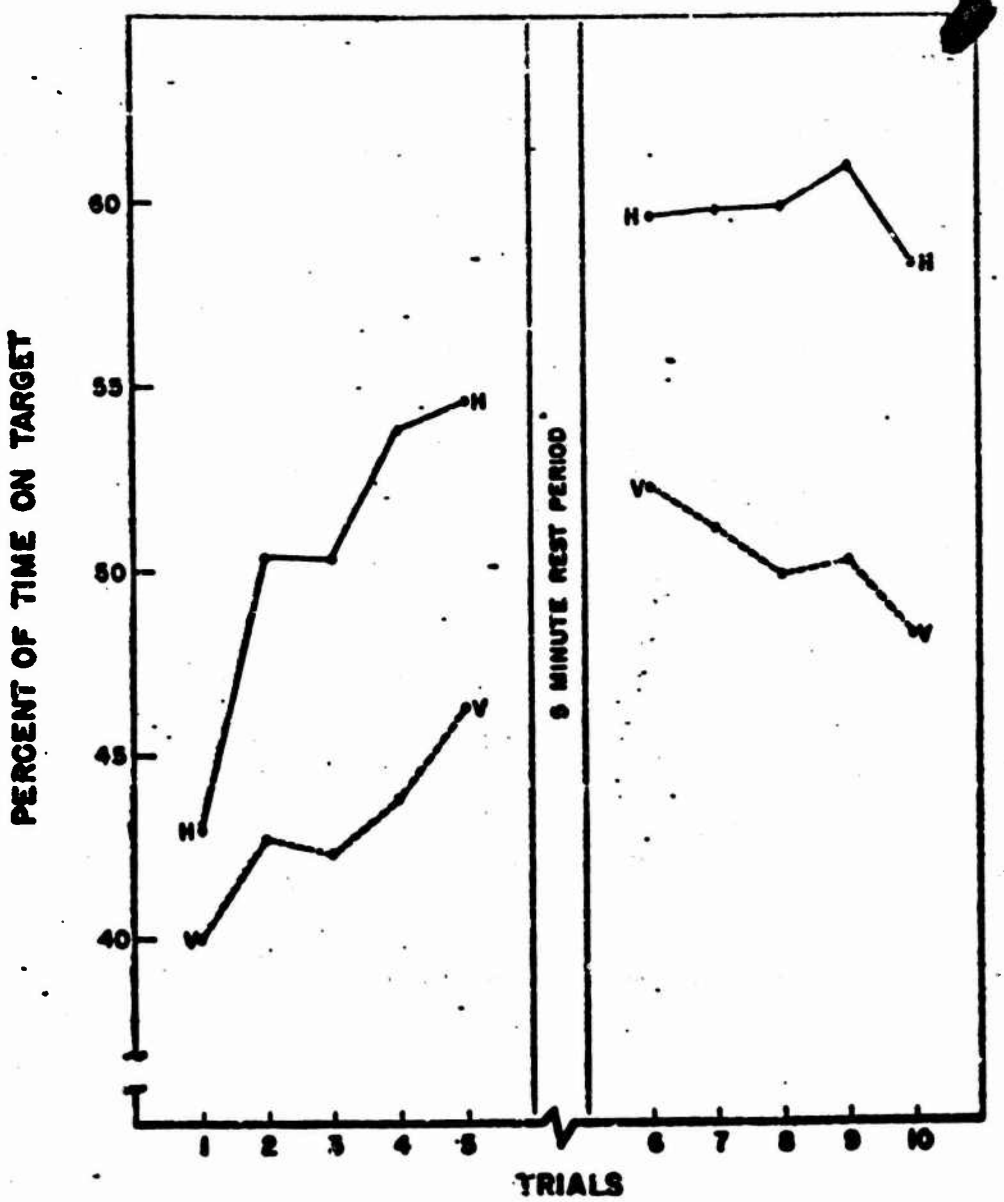

Figure 3. Learning Curves for the Ten Trials of the Two Groups in Experiment 1.

Each point represents the mean performance of twenty subjects, of whom four worked at each of the five different pointer positions.

trials, however, showed a relatively more stable performance level. For this reason only the data for the last five trials were analyzed.[1]

Mean performance scores and standard deviations for each condition are given in Table I. The results of an analysis of variance for these data are summarized in Table II.[2] The variance between mean scores for horizontal and vertical instrument separation was significantly greater than might be expected by chance (<.01 level) when tested by between-subject variance. For the task employed in this experiment it can be concluded that performance with horizontally-separated dials is superior to performance with vertically-separated dials.

Using the pooled interaction of subjects and pointer positions as the estimate of error variance for correlated groups, the variance due to the interaction between the direction of instrument separation and pointer positions was found to be significant at better than the .01 level. This indicates that superior performance with a particular pointer position is in part dependent upon the direction of the dial separation used. The converse is also true.

For the H-group, using horizontally-separated instruments, performance with the 9 o'clock pointer position was better than with the 12 o'clock pointer position (<.05 level) and performance with the 3 o'clock pointer position was better than with the 6 o'clock pointer position (<.02 level).[3]

- - - - -

1 In subsequent experiments the combining of counterbalanced trials in this task was made possible by using shorter test trials that permitted frequent variation in testing conditions, and by continuing the experiment over a period of several days.

2 The technique of analysis used is described by Allen L. Edwards, Chap. 15, Experimental Design in Psychological Research, Rinehart and Co., Inc., New York, 1950.

3 The standard error of the mean difference for these conditions was computed to be 1.034 by using the variance of the pooled interactions of subjects x pointer positions as the best variance estimate for all groups. This estimate of standard error, based on all the data, was used to compute the 't' values, in place of an estimate of standard error of the difference computed separately for each pair of conditions.

TABLE I

Means and Standard Deviations of Performance Scores* for Five Pointer-Position Patterns for the Two Experimental Groups.

(N = 20 Subjects in Each Group)

Horizontal Dial Separation

	H-3	H-6	H-9	H-12	H-X	Means of Rows
Mean	42.5	39.7	45.7	43.5	45.8	43.4
S.D.	7.5	7.1	6.3	5.9	5.8	

Vertical Dial Separation

	V-3	V-6	V-9	V-12	V-X	
Mean	33.8	36.3	35.5	39.2	38.4	36.6
S.D.	7.7	8.9	7.7	8.4	8.4	
Means of Pointer Positions	38.1	38.0	40.6	41.4	42.1	40.0

* Scores represent the percent of time that subjects kept both pointers simultaneously 'on target'.

TABLE II

Analysis of Variance in Experiment 1.

Source of Variation	Sum of Squares	d.f.	Mean Square	F
Between Dial Separation	22.99	1	22.99	9.82
Between Subjects With the Same Dial Separation	88.86	38	2.34	--
Between Pointer Positions	5.52	4	1.39	*
Interaction of Pointer Positions and Dial Separation	3.47	4	.87	8.13
Interaction of Pooled Subjects and Pointer Positions	16.24	152	.107	--

* See the text for a discussion of a further analysis of this factor.

For the V-group the converse was true. The 12 o'clock pointer position was superior to the 9 o'clock position ($<.01$ level), and the 6 o'clock position was better than with the 3 o'clock position ($<.05$ level).

Performance with the counterpoised pointers (X condition) ranked first in absolute score and was not significantly different from the best pointer position for both directions of dial separation.

For both horizontal and vertical dial separations considered separately, the 9 o'clock pointer position was superior to the 3 o'clock, and the 12 o'clock was superior to the 6 o' clock position. Three of these differences were significant at the .02 level, but one (9-3 o'clock vertical) was not significant. Since the data were not suitable for a three-dimensional analysis of variance, a subtraction procedure was adopted as a means of testing the differences in pointer position independent of other factors. Mean scores were obtained for the two conditions (H-3 and H-9) in which both the instruments and pointers were aligned horizontally. In a similar way means were determined for the two conditions (V-6 and V-12) of vertical alignment of pointers and instruments; for the two conditions combining unaligned pointers with horizontal dial separation (H-12 and H-6); and for the combinations of unaligned pointers and vertical dial separation (V-9 and V-3). The two counterpoised conditions were not used in this analysis, since there were no corresponding conditions of unalignment.

Subtracting these respective means from the appropriate original scores of the individual subjects removed the effects of direction of dial separation and of alignment versus unalignment from the pointer-position scores. Subjecting the residual or difference scores to a simple analysis of variance for correlated groups gave a value for F of 7.57 which with 3 and 117 degrees of freedom is significant at better than the .01 level.

The results of this analysis of pointer positions, with the effects of dial separation and pointer alignment removed, are shown in Table III. It is apparent that 9 and 12 o'clock pointer positions are both superior to 3 and 6 o'clock pointer positions, but that the members of each pair are not significantly different from each other.

Intercorrelations between scores made at the various pointer positions on the second series of trials by the H- and V-groups were computed. The median intercorrelation for the H-group was .74 and for the V-group was .86. These moderately high intercorrelations suggest that factors common to an individual's performance on a pursuit task contribute a good deal of weight to his score no matter what pointer position is used.

TABLE III

Values of t* for Adjusted Mean Differences Between Pointer Positions in Experiment 1.

(Based on adjusted means, with effects of dial separation and pointer alignment removed)

d.f. = 39

	6 o'clock	9 o'clock	12 o'clock
3 o'clock	-0.517	2.794**	3.349**
6 o'clock		3.311**	3.865**
9 o'clock			.555

* Plus values indicate that the mean performance of the pointer position on the abcissa was greater; minus values, that it was smaller.

** Significant at the .01 probability level or better.

IV. EXPERIMENT 2: EXTENDED LEARNING STUDY COMPARING 9 AND 12 O'CLOCK POINTER POSITIONS

A second experiment was undertaken to determine more precisely than was done in the first experiment the relative effectiveness of the 9 o'clock versus the 12 o'clock pointer positions for instruments separated horizontally and for instruments separated vertically. Only these two patterns of pointer arrangement were studied because the results from the first experiment, as well as the findings of other investigators, show conclusively that performance is maximized by the use of these positions. The experiment was also planned to reveal whether or not the differences attributable to pointer position would persist throughout an extended learning period.

Procedure.

The apparatus was the same as that employed in the first experiment with the exception that the effective width of the 'on-target' scoring area was reduced. This increased the difficulty level and provided a task on which subjects could continue to show improvement during a period of extended practice. The center points of the instruments were always separated by eight inches.

Fourteen individuals worked on the learning task for 20 days, 40 minutes per day. Each subject worked at the same time each day for the first five days of each week. No trials were run on Saturdays and Sundays.

Subjects were assigned to one of two groups. One group, consisting of four men and four women, worked for the first 15 days with the instruments separated horizontally and for the last five days with them separated vertically. They will be called the H-V group. Another group, consisting of three men and three women, worked for the first 15 days with instruments separated vertically and for the last five days with them separated horizontally. They will be called the V-H group.

Individual trials lasted for 70 seconds. The first 10 seconds constituted a warm-up period during which no score was recorded, but this was not known to the subjects. Fifty-second rest periods were used between trials. Twenty trials were given to each group each day. The conditions for the initial trial each day was counterbalanced between subjects and between days. The instructions to subjects were essentially the same as in Experiment 1.

Subjects were told their scores at the end of each trial. Midway through each daily series of trials they were complimented on their progress and told that they should try to achieve an even higher level of performance. Daily scores were plotted on a chart for comparison with other subjects. It appeared that subjects were highly motivated throughout the four weeks of the experiment.

Results.

In Figure 4 summary learning curves are given for the two groups.

The means for the eight subjects in the H-V group favored the 9 o'clock position for all 15 days of work under the horizontal condition. The means for the six subjects in the V-H group favored the 12 o'clock position throughout all of the 15 days of vertical separation. The smallest absolute and the smallest relative differences between means occurred on the first of the 15 days for both groups.

These data support the previous conclusion that pointer alignment at the 12 o'clock position gives superior performance for vertical instrument separation, and that horizontal pointer alignment at the 9 o'clock position gives superior performance for horizontal instrument separation. The absolute difference was greater in the case of the vertical condition.

Tests of the significance of the differences between pointer positions for each subject were made for the means of successive five-day periods. These results are presented in Table IV. In general, the significance of the differences increased from the first to the second five-day period, and showed no appreciable change during the third five-day period. The evidence indicates, therefore, that the relative differences due to the combined effect of pointer position and dial location persist through an extended learning period.

When the direction of dial separation was reversed for the two groups on the last five days of the experiment, all 14 subjects evidenced a change in performance in the predicted direction. All eight subjects who changed from horizontal to vertical conditions subsequently earned relatively higher scores on trials where pointers were aligned at the 12 o'clock position. Three of the subjects who shifted from the vertical to the horizontal condition, however, continued to give relatively higher scores when working at the 12 o'clock pointer position, although in all three the difference in favor of 12 o'clock was reduced in comparison to what it had been before the shift in experimental conditions. In general, then, the evidence obtained on reversal trials further substantiate the findings from the first fifteen days.

This experiment, although designed primarily to test other

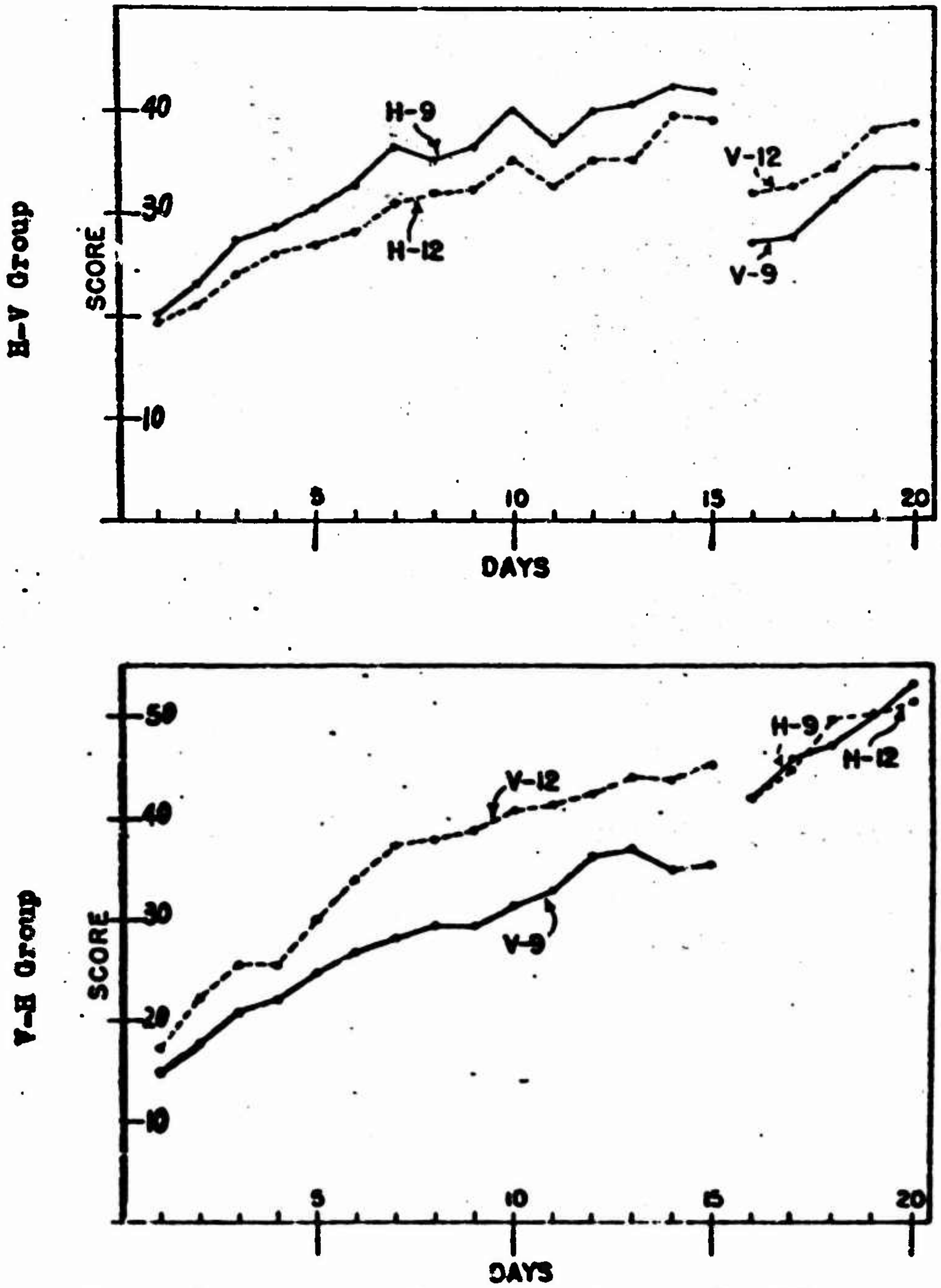

Figure 4. Learning Curves for the Two Experimental Groups in Experiment 2.

Each point on each curve is the average of all trials for a given day (i.e., 10 trials per subject). The H-V Group worked for the first 15 days with the instruments separated horizontally, and for the 16th through the 20th days with them separated vertically. The V-H Group worked for the first 15 days with vertical separation, then changed to the horizontal condition.

TABLE IV

Values of 't'* for Differences Between Each Subject's Mean Scores** on 9 and 12 o'clock Pointer Position in Experiment 2.

(Each 't' is based on 50 sets of scores for a given subject)

Subjects in Group H-V	Days 1-5	Days 6-10	Days 11-15	Days 16-20
M 1	.68	2.15	2.34	- 6.53
M 2	8.67	11.62	10.22	- 6.39
M 3	4.33	3.66	1.84	- 2.33
M 4	7.69	10.59	12.13	- 1.18
F 5	1.42	1.54	- .42	- 6.69
F 6	1.04	4.22	4.19	- 6.03
F 7	2.05	3.64	4.93	- 5.06
F 8	4.01	4.56	3.29	- 4.14
Subjects in Group V-H				
M 9	- 4.12	- 6.26	- 5.03	2.26
M 10	- 5.01	-17.64	- 15.65	- .69
M 11	- 4.74	-10.30	- 5.53	13.11
F 12	- 8.58	-11.59	- 8.82	3.46
F 13	- 7.08	- 9.74	- 14.63	- 8.94
F 14	- 3.79	- 8.61	- 8.55	- 3.33

* Negative "t's" indicate that the 12 o'clock pointer position was superior to the 9 o'clock pointer position; positive "t's" indicate that the 9 o'clock pointer position was superior to the 12 o'clock pointer position. Values of "t" of 2.01 or greater are significant at the .05 level.

** Each mean is based on 10 trials per day for five days.

factors, also provides two comparisons of performance under vertical versus horizontal dial separation. Direct comparisons between the two groups is hardly justified because of the small numbers in each group. Comparisons can legitimately be made within individuals, however, before and after the reversal of conditions on the 15th day. The results for individuals agree with the findings from the first experiment. Subjects who shifted from the horizontal to the vertical condition showed a drop in score and during the next five days never regained their former level of performance. All individuals who shifted from vertical to horizontal, however, quickly exceeded their previous scores.

V. EXPERIMENT 3: THE EFFECT OF THE EXTENT OF INSTRUMENT-SEPARATION ON PERFORMANCE

The third experiment was planned to determine how performance in the dual pursuit task is affected by changes in the distance between instruments. Both horizontal and vertical separation were studied.

Procedure.

The same apparatus was used as in the previous experiments. New instrument panels were constructed to permit the experimenter to use a separation of 4, 8, 12, or 16 inches between instruments, as measured from the tips of the two aligned pointers.

Twelve college men, with normal vision, were used as subjects. None had ever operated the apparatus before.

The instructions were essentially the same as in the two previous experiments. In order to encourage different subjects to use similar procedures, all were told to move their eyes back and forth between the two instruments.

Each subject was tested at the same time of day for six consecutive days. During each daily test period, each subject worked with both vertical and horizontal arrangements of the instruments and with separations of 4, 8, 12, and 16 inches. Two 130-second trials were given for each of the eight unique conditions each day (a total of 16 trials per subject per day). The sequence of test conditions was counterbalanced within and between subjects and between days.

The 12 o'clock pointer position was used when instruments were separated vertically and the 9 o'clock position was used when they were separated horizontally, since earlier results show that these are optimum conditions. The score on each trial was the proportion of time that both pointers were kept 'on target' simultaneously during the recorded period. The 'on-target' tolerance limits were the same as those of Experiment 1. Unknown to the subject, no score was recorded during the first ten seconds of each 130-second trial. Subjects rested for one minute between trials; after every fourth trial there was a two-minute rest period.

Results.

In Table V the individual mean scores are given for each subject based on all trials for all days at each condition. Group medians, means, and standard deviations are also given. The means are also indicated in Figure 5.

In all respects performance was better when the dials were closer together than when they were farther apart. Mean performance scores, for each direction of dial separation, became successively worse with each four-inch increment in the distance between instruments. All differences were significant. In addition, an examination of Table V reveals that each of the twelve subjects, without exception, showed a decrease in average score for each increment in the distance between instruments along both the horizontal and the vertical axes.

In Table VI are shown results for tests of significance ("t" tests) of the differences in mean values for the group and the correlations ("rs") for the various critical comparisons. In all cases performance was significantly better for a horizontal separation of a given amount than for a vertical separation of the same amount. These results were true, without exception, for the average scores of each individual considered separately, as well as for the means of the groups.

The absolute superiority of the horizontal over the vertical condition increased as the distance between instruments increased. For example, for 8-H and 4-V conditions, where the vertical separation was four inches less than the horizontal, the former was superior; but for 12-H and 8-V, where the vertical separation again was four inches less than the horizontal, the latter was superior.

VI. DISCUSSION OF THE FINDINGS FROM THE THREE EXPERIMENTS

The superiority of performance when the two stimulus objects were close together is not surprising. This superiority

TABLE V

Individual Performance Scores* for Four Distances of Horizontal Instrument Separation and for Four Distances of Vertical Separation in Experiment 3.

Subject Number	Horizontal Separation (inches) 4	8	12	16	Vertical Separation (inches) 4	8	12	16
1	55.9	42.9	39.6	34.8	45.2	35.8	26.6	25.0
2	53.8	42.2	38.3	35.0	46.8	36.4	32.4	25.9
3	60.6	49.8	43.8	38.5	51.0	42.6	38.6	35.4
4	65.0	53.8	44.4	40.7	52.4	42.6	37.0	34.0
5	53.4	42.0	41.6	37.7	45.6	38.4	35.8	34.4
6	59.8	51.0	44.4	39.7	51.5	44.0	39.3	34.2
7	62.0	48.8	46.8	42.4	56.3	43.9	35.9	34.0
8	65.2	48.8	42.2	39.4	59.8	43.4	34.3	30.6
9	57.0	42.1	37.7	31.0	44.5	36.0	31.0	29.3
10	62.8	45.2	40.6	36.8	45.5	40.6	32.7	30.3
11	77.0	62.4	57.9	52.1	68.[illegible]	55.8	49.2	45.6
12	62.4	50.6	47.6	42.9	54.2	45.2	41.9	38.6
Group Median	61.3	48.8	43.0	39.0	51.2	42.6	35.9	34.0
Group Mean	61.2	48.3	43.7	39.2	51.8	42.0	36.2	33.1
S.D.	6.4	6.0	5.4	5.3	7.2	5.6	5.8	5.6

* These scores indicate the percent of time that both pointers were kept 'on target' simultaneously.

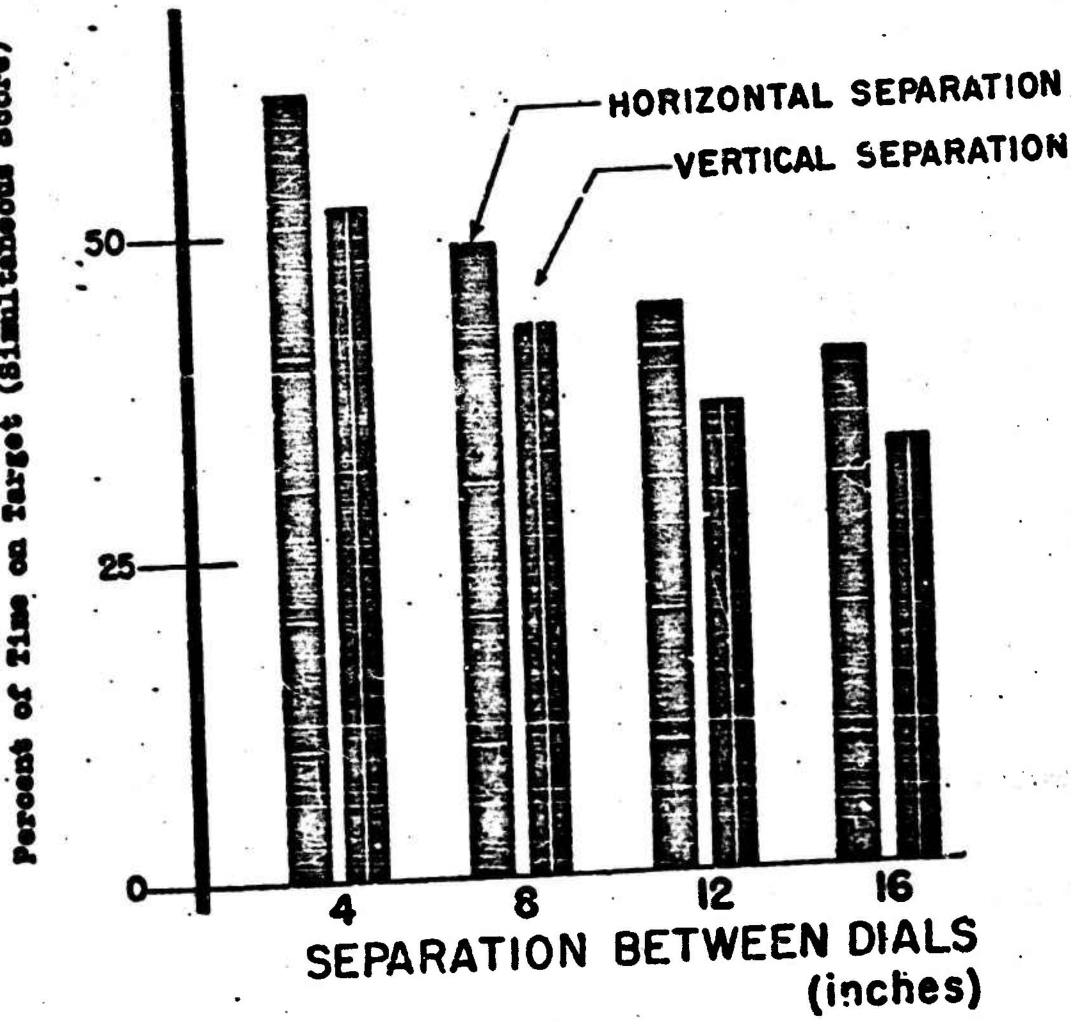

Figure 5. Comparison of Mean Performance Scores for Horizontal and for Vertical Instrument Separation at Four Different Distances.

TABLE VI

Significance of Differences ('t' values) and Correlations Between Performance Scores at Successive Horizontal Distances, at Successive Vertical Distances, and at Corresponding Distances in Opposed Directions

N = 12

	r	t	p
Horizontal Separation			
4 versus 8 inches	.92	17.5	<.01
8 versus 12 inches	.92	6.7	<.01
12 versus 16 inches	.98	15.1	<.01
Vertical Separation			
4 versus 8 inches	.92	11.1	<.01
8 versus 12 inches	.93	9.5	<.01
12 versus 16 inches	.96	6.8	<.01
Horizontal versus Vertical Separation			
4 inches	.89	9.8	<.01
8 inches	.95	11.1	<.01
12 inches	.91	11.1	<.01
16 inches	.88	8.0	<.01

probably is due to the more effective use of peripheral vision, including the use of peripheral cues (a) to provide information for more accurate eye movements, and (b) to provide information for adjustments of the control governing the non-fixated instrument.

Only a very small part of the superiority resulting from stimulus proximity can be accounted for by the saving in time required to make small rather than large eye movements. The eye has a very efficient musculature and is able to execute movements of different amplitudes in approximately a constant time. Furthermore, since eye fixations in the dual-pursuit task are of a duration of the order of magnitude of half a second, while the time consumed by a saccadic movement is of the order of two or three hundredths of a second, the time taken by the latter is relatively unimportant.

More effective use of peripheral vision probably is an important factor also in the superiority of performance under the horizontal-9 o'clock and vertical-12 o'clock conditions, i.e., in the superiority of the alignment over the unalignment conditions. It is proposed that alignment of the stimulus objects makes it easier to detect a movement of the non-fixated pointer. When they are aligned the two pointers can be seen as forming a single line, which breaks up when either pointer goes off target.

Characteristics of eye movements and of the visual field may account for the superiority of horizontal over vertical separation of stimulus objects. Visual acuity is generally better at a given lateral distance from the fovea than at a corresponding vertical distance. Also, in everyday life, people make more frequent use of lateral than of vertical peripheral vision.

The findings regarding the superiority of the left over the right, and of the top over the bottom sectors of a dial is not without parallel. In a series of introspective studies, Dallenbach (3) found that lights located to the left of or above the point of fixation appeared brighter than lights located to the right of or below the fixation point. Recordings of eye fixations made while subjects have looked at pictures, read advertisements, and checked panels of instrument dials have shown that eye fixations are most frequent on the upper and left areas of the visual field. As pointed out earlier, investigators (2, 16) have also shown superiority in the ability to read dials rapidly and make qualitative reports regarding pointer deviations, when pointers were aligned in the 9 and 12 o'clock sectors.

The explanations that have been advanced to account for the observed inferiority of the right and bottom sectors of an instrument dial are based on the hypothesis that direction-of-motion cues are ambiguous when rotary motion occurs in these sectors. In order to account for this ambiguity, we assume that a moving stimulus object, such as an instrument pointer, is responded to in accordance with either a "rectangular-coordinate hypothesis" or a "polar-coordinate hypothesis".[1] If we assume that the two hypotheses lead to the same motor or verbal response for a specified angular position of the pointer, then the two hypotheses will lead to opposite responses when the pointer has passed through an 180° rotation (i.e., is on the reverse side of the dial). As an illustration, a clockwise rotation at 9 o'clock is 'up' and at 3 o'clock is 'down', according to the rectangular hypothesis. This is a situation which Gagne (6) proposes should give maximum negative transfer. For reasons that are obvious, the 9 and 12 o'clock quadrants are those of agreement and the 3 and 6 o'clock quadrants those of disagreement between the two hypotheses.

As indicated earlier, the conditions leading to ambiguity may change with the type of control used and its placement. Simon (12), for example, in a subsequent experiment in this series, has found that when a lever is used in place of a rotary control, the orientation of the lever becomes an important factor; also he has found that when only a single instrument and a rotary control is used, a 12 o'clock pointer position, with the control knob below the display, gives maximum performance. The present results, therefore, probably should not be generalized beyond the common case in which the control is a knob that moves in the same spatial plane as the display and is located below the display, and in which multiple displays and controls are employed.

The ambiguity effect, which is invoked to account for inferior performance at 3 and 6 o'clock, probably is enhanced by the presence of two spatially-separated pointers, such as those used in the present experiments, especially when the two pointers are aligned. Since it would be expected that only those persons responding in accordance with the rectangular (up-down) hypothesis would show negative transfer for the 3 and 6 o'clock positions, this provides indirect evidence that most of our subjects must have responded at times on the basis of this hypothesis, even though the displays and the controls provide a rotary or polar-coordinate system.

1 We do not wish to imply any conscious or verbal activity on the part of the subject.

VII. SUMMARY

1. The effects of various visual stimulus patterns formed by different arrangements of instruments and pointers were studied. Performance in a continuous, dual-pursuit task, in which subjects adjusted two control knobs in order to keep two pointers centered, was used as the criterion of effectiveness.

2. For this task, the results from three experiments are in agreement in indicating that subjects give significantly superior performance when

   a. instruments are close together,

   b. instruments are aligned horizontally, and

   c. pointers are aligned at 9 o'clock for horizontally-separated instruments and at 12 o'clock for vertically-separated instruments, or else the pointers are counterpoised.

3. In the present experiments the controls were below the displays and rotated in the same planes of space as the instrument pointers, a clockwise rotation of a control resulting in a clockwise rotation of its related pointer. These are common relations, but the present results may not necessarily hold when different arrangements or types of controls are employed.

4. The investigators hypothesize that peripheral vision plays an important role in the performance of a task, such as that employed in the present experiments, in which two different stimulus objects are controlled.

5. From a theoretical viewpoint the demonstration that differences in initial performance, due to pointer position pattern, actually increased slightly during fifteen daily practice sessions is especially important. The effect of changes in pointer configuration apparently does not depend on transient unfamiliarity with a given stimulus pattern, but must be attributed to well-established differences in the perceptual-motor capacities for making spatial responses to different kinds of stimulus patterns.

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Antioch College, Yellow Springs, O. Psychomotor Tests

The Arrangement of Instruments, the Distance Between Instruments, and the Position of Instrument Pointers as Determinants of Performance in an Eye-Hand Coordination Task

Fitts, Paul M.; Simon, Charles W. Feb'52 29pp tables, diagr, graphs, drwg

WADC, Research Div., Wright-Patterson Air Force Base, O. (AF Technical Report No. 5832) W33-038-ac-19816

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